BBN Systems and Technologies
A Division of Bolt Beranek and Newman Inc.

(1)

BBN Report No. 7621

MULTIRAD

FINAL REPORT

REPORT DOCUMENTATION PAGE

Form Approved
OPM No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
June 1991

3. REPORT TYPE AND DATES COVERED
Final Technical Report

4. TITLE AND SUBTITLE
Multirad Final Report

5. FUNDING NUMBERS
Contract Numbers:
MDA972-89-C-0060
MDA972-89-C-0061

6. AUTHOR(S)
Author unspecified.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bolt Beranek and Newman, Inc. (BBN)
Systems and Technologies; Advanced Simulation
10 Moulton Street
Cambridge, MA 02138

8. PERFORMING ORGANIZATION REPORT NUMBER
BBN Report Number:
7621

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Advanced Research Projects Agency (DARPA)
3701 North Fairfax Drive
Arlington, VA 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DARPA Report Number:
None

11. SUPPLEMENTARY NOTES
None

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A: Approved for public release; distribution is unlimited.

This report describes

12b. DISTRIBUTION CODE
Distribution Code:
A

13. ABSTRACT *(Maximum 200 words)*

A Simulation Network (SIMNET) project final report of the Multirad network software of the SIMNET hardware and software training system for vehicle crew training and operational training.

14. SUBJECT TERMS
The SIMNET Multirad network software final report.

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Same as report.

NSN 7540-01-280-5500

Standard Form 298, 880922
Prescribed by ANSI Std. 239-18
299-01

DTIC COPY INSPECTED 3

Report No. 7621

Accesion For	
NTIS CRA&I	✓
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

MULTIRAD FINAL REPORT

June 1991

Prepared by:

BBN Systems and Technologies
Advanced Simulation
10 Moulton Street
Cambridge, MA 02138 USA

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

Prepared for:

Defense Advanced Research Projects Agency (DARPA)
1400 Wilson Blvd.
Arlington, VA 22209-2308

This research was performed by BBN Systems and Technologies under Contract No. MDA972-90-C-0061 to the Defense Advanced Research Projects Agency (DARPA). The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policy, either expressed or implied, of DARPA, the U.S. Army, or the U.S. Government.

1 Technical Requirements

1.1 Extend SIMNET Network and Protocols

The extension of the SIMNET protocols to meet the requirements of the air combat application has progressed in two areas. The informal area involved concept development and rapid prototyping to determine where the protocol needed to be enhanced. The formalization of these enhancements via the Distributed Interactive Simulation (DIS) standards process.

1.1.1 RAPID Prototype

The rapid prototype for the protocol extension was demonstrated at the Interservice/Industry Training Systems Conference (IITSC) in Ft. Worth Texas, November 13-16, 1989. Work on the rapid prototype began with informal meetings between representatives of McDonnell Douglas Aircraft Company and BBN on 23 May 1989, three months in advance of the MULTIRAD project funding.

The purpose of the rapid prototype was to integrate a high fidelity aircraft simulator onto the SIMNET network and demonstrate the feasibility of using the SIMNET protocol to interface aircraft simulators over an Ethernet. Appendix A contains the summary of the task that was delivered to HRL in December 1989.

The rapid protype task pointed out that fighter aircraft could indeed engage using the SIMNET protocol, however the protocol was not robust in the support of electronic countermeasures and the specification of aircraft weapons and self defense systems. This observation was confirmed at a technical interchange meeting at McDonnell Douglas Aircraft on xx where a Tactical Air Command simulator training exercise was observed.

1.1.2 DIS Participation

The MULTIRAD program has provided support to the DIS standardization process. This support included participation in general and working group sessions. The DIS process participation included attendance by BBN personnel representing MULTIRAD interests at the symposiums on:

15 January 1990

6 August 1990

January 1991

At the 6 August 1990 sympopsium, a proposal was made by BBN as a representative of MULTIRAD. A presentation of the proposed Radar Emitter PDU are presented in Appendix B.

1.2 Procure, Extend, Install, Test Systems

1.2.1 NIUs

The Network Interface Unit (NIU) was developed from the specification in the customer Statement of Work and the prototype effort undertaken in the fall of 1989 that culminated in the rapid prototype effort for IITSC 1989. The philosophy that motivated the NIU was to develop a service that would easily integrate existing simulators, that were created as stand alone devices, with the SIMNET network. Since the software base to be used for the NIU was 60% extracted directly for the existing body of the SIMNET vehicle simulation software, the critical element was to agree on a interface protocol between the NIU and the device that it was to attach to the network.

The NIU approach was reviewed at the following technical interchange meetings:

System Requirements Review	19 December 1989
Preliminary Design Review	19 March 1990
Critical Design Review	10 December 1990

The NIU/Host interface was developed in two stages:

1) A generic interface for proof-of-principle testing.

2) A device specific interface for each device integrated onto the network via the NIU.

The generic interface was designed and documented in a preliminary specification delivered 9 February 1990. It was revised in a supplementary release 6 June 1990.

The NIU software development using the generic host interface proceeded from the preliminary design review until release to BBN Phoenix, 19 July 1990. Thus ending the first stage.

Specific device interfaces were developed and demonstrated on the following dates:

Cockpit Engagement Trainer	7 September 1990
Ground Control Intercept Station	28 September 1990
McDonnell Douglas Reconfigurable Cockpit	3 November 1990

This second stage has been an ongoing activity with gradual expansion of the capability of each system to interact across the network.

The development of the NIU did not follow rigorous software development practices. In as much as it leveraged the use of existing proven software, as opposed to existing, rigorously developed and tested software, it was a low risk venture.

The concept of a Network Interface service as a seperate logical entity is a good one. A common collection of services that any device may use to interface onto a network running a standardized protocol, should be identically implemented on each device an hence insure the compatibility of the systems across the network. Embodying these services in a seperate piece of hardware, the NIU, has proven to be a less than optimal design. It has induced the creation of many custom interfaces to the network service, where a generic library of functions would have been adequate. The maintenance of these custom interfaces becomes a cumbersome configuration task which will inevidably inhibit the system from taking full advantage of a distributed environment.

1.2.2 Operations and Maintenance Station / NOM

The SIMNET Network Operations and Maintenance (NOM) module was selected to fulfill the requirement for the Operations and Maintenance Station. The SIMNET NOM provides limited power-up and -down capabilities, file transfer functions, and permits the network operator/maintainer to monitor the status of devices on thet network. The NOM performs this monitoring function by listening for regular (e.g., appearance) PDUs from simulators and by listening for specific PDUs in which simulator status is recorded, for example, over-temperature condition or that a simulator is in emergency shutdown. It was agreed by all concerned that with some minimal effort, the NOM would fulfill the lab's needs.

At the time that this selection was made, the SIMNET NOM ran on a Masscomp 5600 computer; however, plans were afoot to port the NOM to a Masscomp 6600 computer. So that the MULTIRAD NOM would be compatible with the new SIMNET NOM, a Masscomp 6600 computer and associated peripherals were purchased and delivered to Williams AFB. Subsequently, the DARPA SIMNET Program Management Office decided not to port the SIMNET NOM to the new hardware platform. It was decided that the MULTIRAD project would not pay to have the SIMNET NOM ported to the new hardware.

At the conclusion of the contract, the Masscomp 6600 and associated peripherals were on-site at Williams AFB. As part of the SIMNET project, "cold-start" materials for the NOM were created which contain all source code for the NOM and instructions on how to compile, link and load the software. A copy of these materials was provided to WAFB.

1.2.3 Long Haul Network (LHN) Gateway

The LHN gateway is a processor and application that serves to link Local Area Networks (LANs). The technical challenge is to seamlessly join LANs that are operating at a relatively high bandwidth (up to 10 megabits/sec for ethernet) via long distance communication channels, such as telephone lines, which are of much lower bandwidth. Seamless implies that interactions between simulators across the LHN is no different from interactions between devices that are on the local network.

The LHN gateway requirements are outlined in the customer SOW. It was determined at the technical interchange meeting in February 1990 that the procurement of a LHN gateway and development related to the LHN gateway was beyond the scope of work for this phase of the program. New developments in Wide Area Network technology, packet switch development, and implementation of the ST Protocol made the investment in current technology less appealing. The requirement to deliver and document such a system was therefor dropped.

A proof of principle demonstration to verify that simulators integrated onto the network at HRL were indeed SIMNET compatible and could interoperate over a LHN was organized in conjunction with other IITSC demonstrations November 3-5, 1990. A synopsis of this activity is presented in appendix C.

The LHN Gateway that was installed at AFHRL was assembled in part from hardware loaned to the demonstration by BBN. Specific parts of the gateway were available only for support of the demonstration and were returned to BBN after the demonstration completed. The items returned to BBN are:

- 2 Butterfly Interface Modules (BIO)
- 1 CMC Ethernet Controller (ENP-30)

To operate the gateway for it's intended purpose, thes items would need to be aquired. In addition, the gateway has a wide variety of user interface tools that would need to be supported. These tools use an Apple computer as the host..

1.2.4 Digital Voice

Initial design began with a meeting involving Alan Oatman and Steve McGarry 8 December 1989. Among the issues was the division of labor between BBN and GE. It was initially decided that GE would likely handle the cockpit interface (DED and heads-up display) and analog circuitry (matching the SIMVAD's levels to the pilot's headset). The software was largely to be a port of the Masscomp-based applicaition that had been done for CECOM, with changes mainly in the controls interface, which now had to go through the NIU. First customer meeting occured 13 December 1989 at Williams AFB. WAyne Marshall promised info on F-16 commo gear, which Alan delivered 8 January 1990. CLient pointed me to ESD at Hanscom, which pointed me to Jim Bradford at MITRE. Met with him on 22 February 1990, at which time he gave me an overview of HAVE QUICK, the UHF system installed in the F-16 as an extension to ARC-164. The CECOM simulation was for VHF, implying changes to the propagation model (a simplification ,actually). The only information I couldn't get was on the hop rate. This was becuase my clearance hadn't been sent to MITRE in time.

Second briefing 19-20 March 1990 at Williams Presented proposal for voice component. Began gatherin headset info from David Clark, starting 5 April 1990. At this point, plan was to implement a standalone interface for demo purposes, using low-impedance (MIL-SPEC) to allow use with pilot headsets. At this point, Dave WHittemore gathering parts and information to design analog interface between headsets and SIMVAD. This headset adapter was tested 19 September 1990 by Paul Metzger with an Army aviation headset, and worked. Headsets from David Clark arrived 20 April 1990. Dave had amp pretty far along by 5 June, deciding to go for non-battery power that day, opting for VME draw instead.

The MVME-147 board was chosen as the CPU, becuase BBN had system software for it, and the NIU was also using it.

Code conversion began in earnest week of 9 July. Installed 19-21 September. System is working, although an alleged packet duplication buyg remains due to lack of funding for repair.

Number one goal for future work is completion of the cockpit interface. GE must be clearly assigned task of getting controls completed and interface to NIU working. BBN must do NIU-to-Voice host interface and controls integration.

1.2.5 MCC System

Due to budgetary and utility constraints, it was decided that no SIMNET MCC system would be delivered as part of the MULTIRAD network.

1.2.6 Message Collec[illegible] Data Analysis

All traffic on the MULTIRAD network may be collected on the SIMNET DataLogger which is installed on the network at WAFB. The DataLogger records all network traffic--including vehicle appearance PDUs, radar PDUs and all others--onto a file on disk. The recorded data may be played back onto the network for subsequent review, or the file may be transfered to a 9-track magnetic tape for off-line analysis.

Due to budgetary constraints, no further SIMNET Data Analysis equipment was purchased for the MULTIRAD network.

1.3 Optional LANs

The original MULTIRAD SOW called for installation of LANs at several sites other than WAFB, including VTRS in Orlando, FL, SIMNET Research Center at Orlando AFB, SCTR at Ft. Rucker, AL, and CCTR at Wright-Patterson AFB, OH. No such installations were ever approved or authorized.

2 Specifications

2.1 ACME Network Interface and Protocol Specification

One of the stated design goals of MULTIRAD was that SIMNET protocols be used wherever possible. The NIU uses an extended version of the SIMNET version 6.6. protocols to pass vehicle appearance and other information over the MULTIRAD network. Where necessary, extensions have been added to pass information, e.g., radar emission information which is required for certain aircraft simulations, but which could not be represented in the basic SIMNET 6.6 protocol. A full description of the SIMNET protocol may be found in BBN Report # 7102, "The SIMNET Protocol" and the addendum document which describes the protocol changes between SIMNET 6.0 and SIMNET 6.6. A detailed listing of the protocol in use at WAFB may be found in the NIU Detailed Design Specification. [Jon Doran-is this correct?]

Also, BBN personnel created a "MULTIRAD Network Design Specification" which includes all details of how the network is constructed. This includes a description of the physical and logical layout of the network, and instructions for operation of all elements of the network.

2.2 Three Subsystems

2.2.1 Network Interface Node (NIU)

BBN personnel at Williams Air Force Base produced a document entitled "Network Interface Unit Detailed Design Specification." This document describes the NIU in complete and exacting detail. Included are sections on NIU overview, hardware and software architecture, and detailed information about each of the software modules and libraries. All parties interested in understanding the workings of the NIU should refer to this document.

2.2.2 Digitized Voice Communications

What we delivered was a basic voice interface which communicated over the simulation network. Tuning can only be done from the simulator's keyboard, since the cockpit interface was never done.

The customer's statement of work was ambitious for the available money. There as constant confusion over the responsiblities of the various contractors, with the client changing assignments constantly. Most notable were the cockpit interface, which GE never built, and the tones generator, resposibility for which shuttled between BBN and GE monthly. After the initial demonstration was completed, demand for features that had earlier been dropped, such as instructor's interface, resurfaced. We ran out of time and out of money.

2.2.3 Gateway

The requirement for delivery of a LHN Gateway specification was deferred. This occured at the intercahnge meeting of 12 July 1990. The decision to defer after determining that LHN capability was a secondary development priority and the technology for Wide Area Networking of simulators was in transition.

3 Engineering Interface Support

BBN personnel at Williams AFB presented technical papers at--and otherwise participated in--several technical interchanges, including the I/ITSC shows in 1990 and 1991 and in several conferences at which the SIMNET protocols were discussed.

Throughout the contract period, perhaps the largest single effort for BBN personnel at Williams AFB was providing day-to-day support of the Williams AFB MULTIRAD network. This included support for many demonstrations of the NIU and the network, participation in meetings with government and contractor agencies to discuss operation of the network, answering questions from outside parties about the MULTIRAD network, etc. BBN personnel created a document titled "Network Operations Procedures;" this document is to be used as an aid to non-BBN personnel to start the computers and run the network. A copy of this document is attached.

BBN personnel in Cambridge performed a study on the use of "dead reckoning" in the SIMNET protocols. AF/HRL provided data (in the form of data from the flight of a flight simulator) and initial funding for this study. When funding for the MULTIRAD project became criticial, it was decided that the dead-reckoning study should be discontinued. BBN continued this study at its own expense, and presented the results of the study at the Fourth Workshop on Standards for the Interoperability of Defense Simulations in Orlando, FL, 13-15 March 1991. A copy of this White Paper is appended to this document.

3.1 Participate in and Present at Technical Interchanges

Technical Interchanges for this project assumed four forms:

- Formal Design Reviews of Project Systems
- Representation of the project at Symposiums and Conferences of the Simulation Community
- Technical Conferences with Subject Matter Experts and Industry Participants
- Informal Status and Direction Sessions

3.1.1 Formal Design Reviews

The formal sessions for the project were:

System Requirements Review	19 December 1989
Preliminary design Review	19 March 1990
Critical Design Review	10 December 1990

The System Requirements Review was a BBN internal peer review where the systems, primarily the NIU, was discussed relative to the SOW requirements, implied requirements, and derived requirements that specified its design. The purpose of this review was to demonstrate that the development philosophy of the NIU was consistent with the distributed simulation methodology.

The Preliminary Design Review was held to inform the HRL user community of the program progress and to review the proposed interfaces to the existing (and developing) devices at the laboratory. It is accepted that the level of detail of the presentations at the PDR was not fine enough in all areas.

The Critical Design Review of 10 December was not a well received nor particularly well prepared event. It was generally viewed as unacceptible in most areas. Following the CDR, the program was re-focused and key individuals were replaced. The program goals were focused on the documentation of the project efforts and development was curtailed.

3.1.2 Symposia and Conferences

Project personnel participated in two major simulation conference activities; the DIS Protocol Standardization effort and the annual IITSC event. Over the course of the program the following events were attended:

DIS Conference	15 January 1990	
	29 March 1990	(Working Group)
	19 July 1990	(Working Group)
	7 August 1990	
IITSC	13 November 1989	
	3 November 1990	

3.1.3 Technical Conferences with Industry Participants

Because distributed simulation is being introduced to the aviation community via the MULTIRAD program, numerous conferences were held with industry leaders in aircraft production and simulation. Primarily these interchanges enabled the exposure of distributed simulation applications to the peer review of knowledgable simulation departments in aircraft manufacturing facilities. These interchanges were held:

McDonnell Douglas	23 May 1989
	28 August 1989
	12 April 1990
General Dynamics	20 April 1990
	28 July 1990
	20 August 1990

In each meeting, distributed simulation protocol issues, such as reflected in the Radar PDU development, were reviewed and critiqued.

3.1.4 Informal Interchanges

Informal interchanges were held frequently after BBN representitives were established on site. The interchanges were held at least twice monthly for the duration of the project at WAFB. Significant meetings were held at BBN Cambridge on 3 May and 12 July 1990.

3.2 Analyze Potential Network Interface Designs

Network media other than Ethernet were researched under the MULTIRAD program. The media explored was the use of the Fiber Distributed Data Interface (FDDI). An FDDI white paper was developed and released on 9 January 1990. This paper was primarily an industry survey that investigated the state-of-the-art in FDDI controllers and the standardization process of FDDI. The conclusions of the investigation were that intelligent controllers were being developed that offered an attractive alternative to the controllers available in January 1990. These would be more suitable to the intended purpose - integration into the NIU.

A second study was provided on 27 June 1990 that outlined a plan to integrate the FDDI controllers into the NIU.

Investigation of FDDI was terminated following the 10 December CDR.

3.3 Evaluate Compliance of Designs to Network

The network protocol compliance of the systems developed under the MULTIRAD program have been proven by demonstration. The interoperability of the new systems with existing SIMNET systems continues to be demonstrated with the operation of the PVD and the Logger on the MULTIRAD network.

No explicit tests were run on the systems to verify compliance.

3.4 Support Integration Testing

The primary role of BBN on site personnel through December of 1990 was the integration support of the CET, GCI, MDRC, and AIT onto the network.

APPENDIX A: I/ITSC RAPID PROTOTYPE TASK SUMMARY

I/ITSC Lessons Learned

22 November 89

Stephen M. McGarry

BBN Systems and Technologies Corporation
Advanced Simulation Division

The goals of the rapid prototype project were:

- to demonstrate the networking of a device not built exclusively by the SIMNET contractors.
- to discover what challenges await those planning to incorporate existing devices on SIMNET.

In the course of integrating the SIMNET protocol into the McDonnell Douglas devices several discoveries were made that bear review by any groups interested in porting the SIMNET Protocol to existing devices. These observations are intended to highlight areas of possible consternation and help to ease the transition.

CONFIGURATION: The system was initially conceived as three MCAIR devices:

- F-15 manned cockpit
- F-18 manned cockpit
- Digital Threat Unit

These three devices are of common computer architecture and were to be linked to allow interaction in an air-to-air scenario using the SIMNET protocols. This configuration would allow for 8 vehicles (2 manned, 6 digital) to be on the network.

Because each system subscribed to a common communication method, the SIMNET protocol standard, the rapid prototype demo evolved into a much more robust demonstration than originally envisioned. The commonality of communication standard with existing SIMNET devices allowed for the interaction with:

- the SIMNET observation vehicle
- the SIMNET Plan View Display
- the SIMNET Data Logger

  The SIMNET Semi-automated Forces via long haul link to Cambridge, MA.

Linking with these pre-existing SIMNET devices substantiates the use of the SIMNET protocol and emphasized the benefits of network compatibility by having these pre-existing SIMNET devices provide:

- GCI support
- Air Defense Vehicles
- Network wide record/replay
- force multipliers via Semi-Automated Forces

all of which were demonstrated on the show floor.

EXERCISE IDs: The Ethernet Network at the I/ITSC show was being shared by several different exercises ranging in size from 8 vehicles (rapid prototype) to several hundred (BBN Semi Automated Forces Demonstration and Logged Exercise Demonstration). These exercises ran simultaneously without interference using an exercise ID contained in the PDU header as a discriminator.

It was noted that the Plan View Display (which can observe all exercises simultaneously, or one exercise only) displayed inadvertent force alignment shifts of the rapid prototype vehicles during replay of a logged exercise. This is attributed to conflicting vehicle IDs between the rapid prototype and the logged exercise. This anomaly is purely the outgrowth of having an omniscient device (the PVD) observing on the network, a tactical device within an exercise adhering to normal protocol practices would have no such difficulty.

UNITS: It cannot be overstressed that the units of measure in the SIMNET protocol are metric and those of most existing aircraft simulators are not. Since unit conversions can be handled in a trivial manner, typically with a multiply, this is not an issue that requires extensive engineering creativity to solve. It does, however, require dogged persistence to insure that the units are always accounted for.

The impact on thruput is a function of the relative capacity of the system. Microprocessor based applications with limited floating point support will tend to pay a more severe penalty than larger hosts. This will be more significant in larger exercises than in smaller ones. A single vehicle simulator will have to allocate more CPU time processing received PDUs than transmitted PDUs in a multiple vehicle exercise.

COORDINATE SYSTEMS: Since the vehicle rotation matrix is a part of the vehicle appearance packet the transformation between an arbitrary frame of reference into and out of the SIMNET frame of reference is a potentially costly one. In a multiple vehicle exercise this transformation must be applied to each appearance packet received and transmitted, with the receive case typically the more demanding.

For the rapid prototype a heuristically derived mapping scheme was utilized that transformed the North-East-Down (NED) coordinate system into and out of the SIMNET system and considerably reduced the thruput required to perform the three dimensional rotations. In general, this issue is best addressed by starting the simulation in the coordinate system expected by the network rather than converti ng at the interface.

STATUS FLAG CONVERSION: Existing simulations naturally have mechanized methods f or noting significant status changes and recording them for the operator (i.e. the fire ball for what used to be a target). The event conversions, which are potentially burdensome, were mapped from the SIMNET definitions into agreed status flags for the host system.

PROTOCOL OVERHEAD: For the rapid prototype system the majority of the overhead associated with converting to the SIMNET protocol at the interface was in the areas of:

- conversion of units
- rotation of coordinate systems
- conversion of status flags
- dead reckoning of vehicles

The observed CPU loading on the 68030 based microprocessor was <= 2.25ms per vehicle at any time during the demonstration.

ETHERNET BANDWIDTH: The exercise that was established involved 8 tactical vehicl es, two of which were manned. The first order dead reckoning model as described in the SIMNET Protocol Description Document was used to reduce the Ethernet bandwidth.

The discrepancy thresholds for the air vehicles were set to 5% of the vehicle dimension in each axis for location, and 1 degree of rotation about each local axis. Since the vehicle were operating at 20HZ, the maximum appearance packet generation was 20 packets per second (pps) and could be generated by a ra pidly maneuvering vehicle. The observed nominal packet rate was approximately 8pps per vehicle. Even with the reduce packet rate pilots were flying formation and tracking targets without difficulty or objections.

DIFFERING FRAME RATES: The MCAIR vehicles ran at a 20Hz frame rate while the BBN devices operated at 15Hz. The skew in the frame rates combined with the dead reckoning model caused an anomaly observed in the BBN observation vehicle, though not in the MCAIR devices. This anomaly manifested itself as target jitter on the Observation Vehicle visual display.

An algorithm for smoothing this jitter was employed on the Observation Vehicle which eliminated all jitter when utilized.

PROTOCOL USAGE: Expediency dictated that the full SIMNET protocol not be implemented in the rapid prototype. Only the minimal subset of elements required to accomplish a suitable exercise were utilized. These elements were exclusively elements of the Simulation Protocol, as opposed to the Data Collection protocol. The PDU's that were implemented were:

- Activating
- Appearance
- Fire
- Impact
- Deactivate

These were found to be sufficient to accomplish the exercise objectives.

INITIAL CONDITIONS: The reset state for aircraft simulations tends to require special coordination between the aero models and the visual system. Likewise, it requires consideration for the visual systems of others on the network, and for network bandwidth in general.

To achieve proper trim, the aero model requires some velocity, trim velocity, which will fix the aircraft attitude. In a reset or freeze state, however, the position of the vehicle is not updated when passed to the visual system. The artifice of an unmoving vehicle that has a velocity causes other vehicles on the network to dead reckon the vehicle away from the freeze position, only to be called back by an appearance update when the thresholds are exceeded. This cycle of continually repositioning a frozen vehicle appears as jitter in other systems on the network.

To alleviate this potential difficulty it is recommended that a velocity of 0 be placed on the network when the vehicle is in a reset or freeze state.

DATABASE CORRELATION: The MCAIR simulators used a different database from the SIMNET devices which resulted in several accommodations.

To enable the representation of aircraft on the ground in both systems, the position of the runway was established and used as an offset constant. This position vector was applied and removed by the MCAIR devices at the interface.

In order to obtain a horizon reference in the Observation Vehicle visual system the altitude of the exercise was brought down to 3000 ft. This is a low altitude for air combat maneuvering exercises.

These compromises were sufficient for obtaining the exercise objectives but could have been eliminated by using compatible databases.

LONG HAUL: Ground targets were added to the exercise via the semi automated forces system located in Cambridge, MA. These were air defense vehicles armed with surface to air missiles. This long haul addition provided a new dimension to the exercise, allowing air-to-ground strikes by the manned simulators against a competent adversary. The diversity was found to be a significant tactical and technical achievement.

APPENDIX B: RADAR PDU DEVELOPMENT

RADAR PDU HISTORY

For the AFHRL ACMENET effort several aircraft simulators will be networked together to perform both multi-ship training and training research. The devices on the network will be of a variety of designs from different manufacturers. They will also be of widely differing levels of fidelity.

The mission to be performed at ACMENET will initially be several many vs. many Air-to-Air scenarios. Currently it is believed that the actual number will be approximately 5-6 live vehicles on each team. More computer generated vehicles will also probably be present. Although that is the vision for the initial goals; the eventual goals go far beyond that capability. They encompass the Air-to-Air battle and may involve hundreds of vehicles or part in a Joint services exercise..

The principle issues for networking in this situation are:

Data Latency between players

Visual system differences in FOV, resolution

Electronic emission data transfer

Weapons Fly-outs and Scoring responsibilities

All of these issues are difficult to solve; and made more difficult by the wide range of capabilities required by the design: The ability to support high fidelity Weapon Systems Trainers interfaced with very low fidelity part-task trainers in such a fashion as to reduce possible impact to the existing devices.

Approach - The design applied required the construction of a new functional module to the network; called a Network Interface Unit. The NIU will allow the existing simulation hosts to dramatically reduce the modification required for network compliance by handling most network specific operations. The design also uses the fact that many simulators have been previously networked using proprietary protocols by offering several interface options. In effect, the NIU will have a tailored interface to the host and a very specific interface to the network (SIMNET-AF).

In order to respond to the electronic emissions that are vital to proper Air-to-Air training exercises, the existing protocol was reviewed for adequacy.

The existing Radiate PDU was created to support experiments with an ADATS weapon system; a ground-based mobile anti-aircraft radar and gun set. The existing Radiate PDU allows intercommunication of the following parameters:

Mode - Search, Acquisition, Track, other

Duty Cycle - Pulsed, Continuous

Frequency of carrier

Signal Power

Energy per pulse

Antenna Gain

list of targets illuminated and detected

This PDU was considered for use in the ACMEnet environment; however it was rejected in its present form for a few reasons.

1. A critical parameter to many Radar Warning Receivers (RWR) is the Pulse Repetition Frequency (PRF) or alternatively the Pulse Repetition Interval (PRI). This parameter is essential to the simulation of RWRs to provide correct operation and response to radar emissions.

2. When a system is able to radiate a large volume, the list of targets illuminated and detected could be enormous. Several training critical systems have capabilities to track more than the existing limit of 33 targets.

3. Many existing Fire Control Radar units operate while changing their transmission parameters almost constantly to prevent unwanted interference; the load to the network and/or host of issuing a new Radiate PDUs while frequency hopping or staggering PRFs would be large. In addition, the hosts receiving the data could be effectively drown by volumes of data regarding other vehicles emissions.

4. Significant modification of the host might be required to force each emitter to list all vehicles illuminated. Typically, only those targets within the current range scale are processed for detection criteria, and in some modes, only specific types of vehicles are considered.

Admittedly, there are several approaches to modify the existing Radiate PDU to resolve the issues raised. The ideas expressed here are the ones being pursued by this author.

In General - In order to resolve issues 1 & 3, an indexing or coding scheme is suggested. One of the drawbacks is that any player on the network must have prior information on any other vehicle that might be encountered. Another is that each new radar unit implemented would require modifications to every players database. Certainly an expensive penalty.

As an attempt to resolve issues 2 &4, it is suggested that the list of illuminated and detected vehicles be maintained TO THE BEST ABILITIES of the host; I don't think it is possible to force the emitter to list each vehicle which will be illuminated. Somehow, though we must specify that there is a priority based on range and possibly vehicle type. Additionally, the host would include parameters to describe the search volume, for players not in their list which are concerned about emissions. Uncertainty is a drawback of this scheme, exclusion from the list of illuminated targets would be meaningless for a player capable of sensing radar emissions.

The current design for a RadarPDU is :

```
type RadarEmission sequence {
      vehicleID          VehicleID,
      location           WorldCoordinates,
      system        RadarSystem,
      mode               RadarMode,
      specificData  UnsignedInteger(64),
      azimuthcenter  Angle,
      azimuthwidth   Angle,
      elevcenter    Angle,
      elevwidth          Angle,
      power         integer,
      numberIllumed  UnsignedInteger(8),
      targetID           array (numberIllumed) of VehicleID,
      data             array (numberillumed) of RadarData
}
```

The field RadarSystem contains the following bit field:

```
bits  28 - 31  -> RadarSystem Category
bits  16 - 23  -> RadarSystem Subcategory
bits   0  - 15 -> RadarSystem ID
```

RadarSystem Categories -

00	-	Reserved (unused)
01	-	Air-Based Fire Control
02	-	Air-Based Search
03	-	Ground-Based Fire Control
04	-	Ground-Based Search
05	-	Sea-Based Fire Control
06	-	Sea-Based Search

RadarSystem Subcategories -

TBD

RadarSystem ID -

00	-	Reserved (unused)
01	-	AN/APG-66 (F-16A)
02	-	AN/APG-68 (F-16C)
03	-	AN/APG-63 (F-15)
04	-	AN/APG-65 (F/A-18)
05	-	AN/APG-70 (F-15E)
06	-	JayBird (MiG-21, Su-24, Su-20/22)
07	-	(MiG-31)
08	-	(MiG-29)
09	-	(MiG-27)
10	-	(Su-27)
11	-	AN/APY-2 (E-3A)
12	-	SUAWACS (IL-76 Mainstay)
13	-	FoxFire (MiG-25)
14	-	HighLark (MiG-23S)

The field mode characterizes the current operation of the system :

```
type RadarMode enum (8) {
    RadarModeSearch,
    RadarModeDopplerHPRF,
    RadarModeDopplerMPRF,
    RadarModeDopplerLPRF,
    RadarModeMonopulse,
    RadarModeAcquisition,
    RadarModeTracking,
    RadarModeTrackWhileScan,
    RadarModeTerrainFollow,
    RadarModeDataLink
}
```

The field specificData is reserved for future more complete information inclusion. The variables azimuthcenter, azimuthwidth, elevcenter, elevwidth all represent the angles required to desribe the volume covered by the radar scan. All angles are assumed to be in vehicle coordinates; with the origin described by the location field. The volume described should correlate to the radar signal indicated by the RadarMode field.

The field power contains the average power per solid angle being transmitted in units of dBm (decibel milliwatts).

The target ID field contains from one to TBD identifiers of vehicles illuminated by the radar. The exact number of vehicle identifiers present is specified by the value in the numberillumed field. The identifiers in the array are prioritized to ensure that all tracked targets appear prior to only search illuminations; and secondly to sort vehicles illuminated by range.

The field RadarData contains the following bit field:

bits 24 - 31 -> RadarMode pertaining to applicable VehicleID

bits 0 - 23 -> Specific RadarSystem/RadarMode data(optional)

[Might be : Polarization, Freq Hopping, Staggered PRF, etc]

APPENDIX C: LAN/LHN DEMONSTRATION

At the 1990 IITSC BBN assembled a LAN/LHN distributed simulation demonstration that included participation from five independant contractors, three government agencies, and three geographic locations. Each participant had a set of goals for the conference andundertook to achieve those goals using a common network.

Demonstrated Capabilities

The system that was assembled for IITSC 90 demonstrated several keyt echnologies:

- Wide Area Networking (Long Haul) of manned fixed wing aircraft simulators.
- distributed interactive simulation using the SIMNET protocol
- digital radio simulation and voice transmission

The three geographic locations or sites that were linked viaterrestrial phone lines to form the Long Haul portion of the demonstration were:

- Marriot World Center, Orlando FL
- Williams AFB, AZ
- Fort Rucker, AL

The Marriot World Center in Orlando was the hub of the network. The bulk of the participants were located in booths on the trade show floor of the conference. The BBN booth housed a gateway that enabled digital communication between the three sites.

The link to Williams was a 56KBit/sec dial up line. At the BBN office at Williams was a single gateway that received data from Orlando and transmitted data to Orlando. The link to Fort Rucker was a T1 (1.5 MBit/sec) line. This site also had a single gateway that communicated with the BBN booth in Orlando.

```
                 Ft. Rucker AL
                   |
                   | 56Kb
                   |
                   |
Williams,AFB              Marriot World Center
Phoenix, AZ ------------------ Orlando FL
          T1
```

Figure 1. Geographic network topology.

Devices in Orlando

There were a large number of participants on the LAN at IITSC 90 and the locations of their booths made the job of linking them in a trade show environment difficult but not insurmountable. The LAN in Orlando was run, for convenience, over 75 ohm coax between the booths. Since the maximum length specification for a single LAN would be exceeded, due to the locations of the boots, an ethernet repeater was used across the longest legs. There were no adverse effects observed due to this configuration.

The LAN ran between five booths on the show floor:

- BBN
- General Dynamics
- Air Force Human Resources Laboratory
- Paragon Graphics
- TSI

The hub of the network was in the BBN booth where the Long Haul Links were located and all of the LAN legs terminated. The following is a brief description of the devices located in each of the booths that participated in the distributed exercise.

BBN Devices

On the network at the BBN booth were:

- 56Kb Gateway
- T1 gateway
- Semi-Automated Forces Workstation
- Observation Vehicle
- Digital Voice System

The gateways were physically housed in a single GP-1000 system but were logically seperate. They provided the digital links to Williams, AFB AZ over the 56Kb portion and to Ft Rucker AL over the T1 portion.

General Dynamics Device

The General Dynamics booth had an F-16 flight simulator on the network. Though it represented only one entity, its complexity is worth presenting here.

The F-16 simulation host consisted of three Silicon Graphics Workstations - a 220 and two personal IRISs. These devices computed the vehicle dynamics and provided the weapons system simulation as well as the pilot/vehicle interfaces. Only the 2-dimensional output of the graphics displays of the Silicon Graphics Workstations were used. These provided overlays of the out the window HUD display as well as the head down multi function displays (MFDs).

The four out the window graphics channels as well as the Maverick seeker video was provided by two BBN GT-120s. These were interfaced to the host over ethernet via the BBN provided Network Interface Unit NIU. The NIU also provided the host interface to the SIMNET network and housed the Digital Voice System compatible with that in the BBN booth and at the remote sites.

The GT-120s served as the master clock for the NIU. They were run at 15Hz during the demonstration, though during development they were run at 30Hz. The Silicon Graphics system that served as the simulation host did not have a fixed frame rate and ran asynchronous to the NIU and the CIGs.

The General Dynamics simulator exchanged the following simulation protocol variants across the SIMNET network:

- Vehicle Appearance
- Fire
- Impact
- Deactivate

The term 'exchanged' is defined to mean that the device received and interpreted the varient from other network entities as well as sent the ownship state/event variants.

The General Dynamics simulator transmitted the appearance variants for itself as well as the air-to-air and air-to-ground missiles that were launched by the vehicle. The missile dynamics were computed by the Silicon Graphics simulation host as well as the tracking and targeting algorithms. To maintain compatability with the existing devices on the network, the vehicle type ADATS missile was substituted for the AIM-9. This enabled the use of the existing SAF and manned simulators, without modifying the damage tables in each device.

The ballistic trajectory for the 30MM gun that was part of the F-16 weapons system was computed by the master GT-120, as were the impact events generated by gun employment.

The NIU provided the host with several services related to the network beyond translating the information to and from the network. The NIU provided dead reckoning of the appearance of other vehicles. The list of other vehicles was prioritized by vehicle type and range and was clamped to thirty vehicles total. This clamp was added in response to degraded host performance as the other vehicle list got larger than 30.

Air Force Human Resources Laboratory

AFHRL demonstrated the networking of several devices:

- F-16 Combat Engagement Trainer (CET)
- Ground Control Intercept Station (GCI)
- Plan View Display (PVD)
- Data Logger

The CET is a VME based system used to train pilots in the weapon system employment of the F-16. It was integrated to the SIMNET network via an NIU with Digital Voice System.

The GCI station is a Sun Workstation based device used to present the radar imagery to the GCI controller. This device was also interfaced to the SIMNET network using an NIU with Digital Voice System.

The PVD and the Logger are the standard BBN developed Concurrent based devices.

Paragon Graphics

Paragon Graphics borrowed the Rapidly Reconfigurable Cockpit (RRC) from the Air Force Human Resources Laboratory and integrated it with their visual system. The RRC is a VME based system used to train pilots in the employment of the weapon systems of the F-15, F-18, or F-16. The RRC was interfaced to the SIMNET network using an NIU with Digital Voice System.

TSI

TSI had two IBM-PC based systems connected to the SIMNET network. One device was a monitor type system similar to the Observation Vehicle. The other was a vehicle generating system, capable of simulating multiple vehicles and placing them on the network.

TSI interfaced to the network directly and did not use an NIU. They did not participate actively in the exercise and did not need a digital voice link. Unfortunately, they were unable to present a vehicle on the network using the vehicle generator, but they were very sucessful in monitoring the exercise from their network monitoring system.

Devices at Ft Rucker, AL

The LAN at Ft Rucker included the FWA and RWA simulators introduced earlier in this paper. These devices, by nature of their design, are fully SIMNET protocol compliant. The interoperation of these devices over the long haul was transparent to the devices on the LAN in Orlando. The FWA and the General Dynamics F-16 simulator were able to operate as an element to engage air and ground forces. They flew in combat formation using visual reference, communicated over the digital voice network, performed rendevous maneuvers directed by FACs, and perform as a Joint Aerial Attack Team with the RWA also located at Ft Rucker.

Devices at Williams AFB, AZ

Along with the gateway, AFHRL operated a CET device, identical to the one in the AFHRL booth, on a LAN at Williams. This device was able to perform beyond visual range intercepts with the device in Orlando.

Network Analysis

The exercise bandwidth was not explicitly measured. Each NIU equiped device conformed to the first order DR algorithm. From previous studies the typical bandwidth required is 1kbit/second for a ground vehicle and 6kbits/second for an air vehicle. The voice traffic consumes 20kbit/second. On this basis the approximate ethernet bandwidth consumed during the demonstration was less than 150kbits/second on average. Since this would saturate the 56kbit line to Williams, the exercises were segregated accordingly.